The Thesis Committee for Kristin Marie Abels
Certifies that this is the approved version of the following thesis:

The Impact of Foam Rolling on Explosive Strength and Excitability of the Motor Neuron Pool

APPROVED BY
SUPERVISING COMMITTEE:

Supervisor:

____
Lawrence Abraham

____
Jody Jensen

The Impact of Foam Rolling on Explosive Strength and Excitability of the Motor Neuron Pool

by

Kristin Marie Abels, B.S.Athl.Trng.

Thesis

Presented to the Faculty of the Graduate School of

The University of Texas at Austin

in Partial Fulfillment

of the Requirements

for the Degree of

Master of Science in Kinesiology

The University of Texas at Austin

August 2013

Dedication

To my mentor and supervisor Dr. Larry Abraham. I couldn't have done it without you.

Acknowledgements

Thanks to Dr. Jody Jensen for the use of her lab and her assistance as a second reader.

Special thanks to Dr. Edmund Emmer for his statistical expertise.

Abstract

The Impact of Foam Rolling on Explosive Strength and Excitability of the Motor Neuron Pool

Kristin Marie Abels, M.S.Kin.

The University of Texas at Austin, 2013

Supervisor: Lawrence Abraham

Abstract: To assess acute performance-related effects of foam rolling, this study investigated the immediate effects of a standard foam rolling protocol on explosive strength of the plantarflexors and alpha motor neuron excitability in the soleus. Explosive strength was measured via vertical jump height (JUMP) and the Reactive Strength Index (RSI) obtained from a single leg drop jump. Alpha motor neuron excitability was measured by H reflex amplitude as H wave to M wave ratio (HM) obtained from the soleus muscle. JUMP and RSI measures were analyzed from nineteen subjects (12 male, 7 female) HM data were analyzed from 15 subjects (9 male, 6 female). Subjects attended one day of practice and instruction for the single leg drop jump and one day for data collection. One leg was randomly assigned to be the test leg (FL) and the other as the control (NL). The reported dominant leg and gender were also recorded for each subject. Subjects performed two single leg drop jumps per leg from a box height of 30 cm and then 10 soleus H reflexes were obtained. The intervention, which followed standard professional guidelines, consisted of 2.5 min of foam rolling for the FL and rest for the

NL, followed by a 5 min warm up on a cycle ergometer. The best jump and the average HM ratio were chosen for analysis. For each variable a post/pre ratio was calculated for statistical analysis. A 2x2x2 factor ANOVA with repeated measures on both factors was used for each variable. Analysis revealed no statistically significant differences for any of the variables, either as main effects or any of the interaction effects. Subjects trended towards a slightly larger post-intervention decrease in JUMP and RSI for the FL than the NL but this was not significant. It was concluded that a 2.5 min intervention of foam rolling had no acute effect on explosive strength of the plantarflexors or alpha motor neuron excitability of the soleus.

Table of Contents

List of Tables

List of Figures

Chapter 1: Introduction and Background

1.1 Introduction

The world of athletics is a high-paced, rapidly growing, and business driven field. In 2010 during the middle of the recession, forbes.com reported that the average value of a team from the National Football League was $1.02 billion (Badenhausen, Ozanian, & Settimi, 2010). The University of Texas at Austin Athletics Department gives an average of $8.5 million in scholarships a year and generates enough revenue to fund itself without university support ("Budget Facts," 2011). With millions to billions of dollars on the line in revenue and scholarships, athletes and coaches are trying everything they can to gain an edge over the competition. One of the newest and fastest growing trends in athletic performance enhancement is foam rolling.

Marketed as a cheap manual therapy tool, foam rolling has exploded in popularity in the past decade. Its enormous success has prompted the formation of companies which specialize in the production of foam rollers and other similar products for self-applied deep tissue manipulation. High demand for foam rollers has even prompted wholesale distributers like Wal-Mart, Target, and Academy to sell them in their stores. Foam rolling is also endorsed by the National Academy of Sports Medicine as an effective soft tissue therapy incorporated in their Corrective Exercise Training program (Clark & Lucett, 2010)

Foam rolling's appeal to the athletic population is perpetuated by its ease of use. In foam rolling, the athlete lies across a foam cylinder (see Figs. 1 and 2) and, using body weight to control the pressure, rolls the cylinder along a muscle, beginning distally and moving proximally (Clark & Lucett, 2010; Macdonald et al., 2012). It is commonly recommended for use by athletes as part of a pre-event warm up because it claims to improve muscular performance by restoring length-tension relationships within the muscle, improving force couple relationships, and correcting abnormal joint motion (Clark & Lucett, 2010) that results from microtrauma to the muscle and fascia during exercise, in much the same way that myofascial release (MFR) is believed to work (Clark & Lucett, 2010; Lavelle, Lavelle, & Smith, 2007).

Figure 1: Examples of foam rolling

Figure 2: Types of foam rollers

However, there is no research supporting these claims (Macdonald et al., 2012). In addition, studies investigating SMR, the purported physiological mechanism behind foam rolling, have mainly looked at its long term effects on range of motion. There have been no studies investigating its acute effect on explosive strength, also sometimes called explosive strength, nor has any study investigated the validity of the theoretical physiological mechanisms underlying foam rolling. The recent explosion in popularity of foam rolling and its endorsement from the National Academy of Sports Medicine warrant an investigation of the acute effects of foam rolling.

1.2 Technical Discussion

To place foam rolling in the context of sports medicine and rehabilitation, one must first understand the principles and study of ischemic compression (IC) and myofascial release.

Ischemic Compression

More broadly, IC refers to a technique that places pressure on the tissues to a degree severe enough to result in temporary ischemia, or a lack of blood flow, to the compressed area (Lavelle et al., 2007; Montañez-Aguilera et al., 2010). The purpose of this method is to increase local blood flow upon release, which is thought to facilitate the removal of waste products, supply oxygen, and promote healing of the tissue (Montañez-Aguilera et al., 2010). IC can be applied to both large and more localized areas of muscle.

Myofascial Release

One subset of IC is MFR. MFR is a localized form of IC applied to adhesions or ‘knots’ in the muscle, called trigger points because the muscle reacts to pressure applied to them. In MFR a manual therapist searches the muscle belly for trigger points and then applies direct sustained pressure to the area until a release is felt (Lavelle et al., 2007; Schleip, 2003a). There are multiple theories on the physiological mechanism underlying MFR that causes this palpable release. The most widely accepted explanation is that MFR works by influencing the autonomic nervous system (ANS) and central nervous systems (CNS) through the stimulation of mechanoreceptors embedded in the compressed fascia in and around the muscle.

Autonomic Nervous System

Pressure applied through MFR is believed to activate the autonomic nervous system by stimulating interstitial type III and IV receptors which respond to light touch (Mitchell & Schmidt, 2011) and the Ruffini endings in the fascia that respond to deep sustained pressure (Clark & Lucett, 2010; Schleip, 2003a, 2003b). MFR proponents argue that stimulating these receptors lowers overall sympathetic tone (Berg & Cabri, 1999; Clark & Lucett, 2010; Johansson, 1962; Schleip, 2003a), increases gamma motor neuron activity (Berg & Cabri, 1999; Clark & Lucett, 2010; Schleip, 2003a), and promotes the relaxation of intrafascial smooth muscle cells (Schleip, 2003b). In addition, it is believed that the autonomic nervous system promotes vasodilation and local fluid dynamics which alter the viscosity of fascia by changing the ground substance to a more gel-like state (Clark & Lucett, 2010; Delaney, Leong, Watkins, & Brodie, 2002; Schleip, 2003b). All of these combined effects are hypothesized to yield a palpable release of the trigger point and improved muscle function.

Central Nervous System

The involvement of the central nervous system in MFR is more clearly understood than that of the autonomic nervous system. Put simply, stimulation of the mechanoreceptors activates both the autonomic nervous system and the central nervous system simultaneously. The CNS response to such localized pressure is well known to include changing the tonus of a few related striated muscle fibers (Schleip, 2003b). This contributes to the release felt through application of MFR.

Trigger Points

Trigger points are areas of muscle that become taut and appear to adhere themselves to surrounding tissue. Practitioners believe that trigger points can develop as a result of repeated microtrauma to the muscle (Clark & Lucett, 2010; Lavelle et al., 2007) like that sustained from daily exercise. It is hypothesized that these trigger points shorten the muscle resulting in a weak inelastic matrix that decreases the elasticity of surrounding soft tissue (Clark & Lucett, 2010). This causes an altered length-tension relationship within the muscle which can lead to altered reciprocal inhibition, altered force-couple relationships, and abnormal joint motion (Clark & Lucett, 2010; Gossman, Sahrmann, & Rose, 1982), all of which are hypothesized to negatively impact athletic performance (Clark & Lucett, 2010).

Foam Rolling/Self Myofascial Release

Self-myofascial release (SMR) utilizes the same rationale as MFR except the subject performs the release to himself through the use of an object, usually a foam roller. In foam rolling, the athlete lies on a foam cylinder and, using body weight to control the pressure, rolls the cylinder along a muscle beginning distally and moving proximally (Clark & Lucett, 2010; Macdonald et al., 2012). It is commonly used by athletes as part of a pre-event warm up because it is thought to improve muscular performance by removing trigger points and re-establishing normal muscle function (Clark & Lucett, 2010).

1.3 Related Literature

To date, there has been no research done on the acute effects of generalized IC on explosive strength. The majority of IC articles have investigated post-exercise recovery and lactic acid uptake. The purpose of this study is to investigate acute effects of foam rolling on neuromuscular mechanisms and performance.

Myofascial Release

While there are multiple research reports on the long term effects of MFR and its influence on range of motion, few studies exist on the acute effects of MFR. Two studies that investigated the acute effects of MFR on strength found different results, with one citing beneficial effects to strength (Lin, Chou, Chen, & Kao, 2012) and the other citing no effect (Roach, Sorenson, Headley, & San Juan, 2012). The remaining two studies investigated the effect of MFR on basal myoelectrical activity. Both found a significant decrease in basal myoelectrical activity immediately following MFR (Aguilera et al., 2009; Montañez-Aguilera et al., 2010). No published reports have investigated explosive strength.

Foam Rolling/Self-Myofascial Release

One question surrounding the efficacy of foam rolling is whether it supplies enough force to the treatment area to induce the physiological mechanisms attributed to MFR. However, the minimal surface pressure needed to stimulate interstitial receptors III and IV and Ruffini endings has not been reported. There have been studies done on the forces needed to induce mechanical changes in fascia. Threlkeld (1992) claimed that some, but not total, permanent elongation in fascia begins when it is deformed to 3% of its initial length. It was calculated that the mass component of force required to produce this change was between 24-115 kg (Threlkeld, 1992). However, Sullivan et al (2013) found that the average mass component of force exerted by a foam roller on the hamstrings by an individual supported by body weight was 13 kg. While this does not meet the minimum force cited in Threlkeld, only one type of foam roller was tested by

Sullivan et al., thus this does not rule out the possibility that other foam rollers of higher densities could produce the minimum force necessary. Curran et al. (2008) attempted to calculate the pressure exerted on soft tissue by two different types of foam rollers. It was determined that foam rollers made of harder material were significantly better in increasing soft tissue pressure and isolating the contact area (Curran, Fiore, & Crisco, 2008; Macdonald et al., 2012). However, the study took its measurements in kilopascals and did not provide enough information for the values to be converted into kilograms. Thus, it can't be compared to the findings in Threlkeld (1992) or Sullivan et al. (2013).

To date, only four studies have investigated the acute effects of foam rolling. One study found that foam rolling significantly reduced vascular stiffness and improved endothelial arterial function, providing supporting evidence to the theory that foam rolling improves blood flow (Okamoto, Masuhara, & Ikuta, 2013). However, this study did not look at how this affected any aspect of muscular performance. The second study by Sullivan et al. (2013) found that foam rolling resulted in a significant increase in hamstring range of motion with no effect on maximal voluntary contraction, twitch force, and electromechanical decay measured through surface electromyography (K. M. Sullivan, Silvey, Button, & Behm, 2013). Again, this study provided no information on the acute effects of foam rolling on mechanical muscular strength or explosive strength. Healey et al. (2013) attempted to investigate the acute effects of foam rolling on explosive strength measured through a vertical jump height. They found that there was no difference in athletic performance when foam rolling was compared to various planking exercises (Healey, Hatfield, Blanpied, Dorfman, & Riebe, 2013). However, the study did not adhere to current foam rolling recommendations that a constant pressure be maintained for a minimum of 30 s. In addition, testing was carried out over the course of two days which does not eliminate any possible learning effect or carryover effect from foam rolling. MacDonald et al. (2012) is the only published study on the acute effects of foam rolling on muscular strength. They found that two minutes of foam rolling to the quadriceps was not sufficient to produce any changes to force production measured at two and ten minutes post intervention despite a statistically significant increase in range of motion. MacDonald et al. (2012) cited and compared the results of their foam rolling study to the results of previous pre-event massage studies, claiming similar observed effects. Since MFR is not only a subset of IC but also of massage, this fact and the claims in MacDonald et al. (2012) warrant a discussion of massage literature.

Pre-Event Massage

There are some pre-event massage studies that reported similar findings to MacDonald et al. (2012), citing no effect on strength and power (Brummitt, 2008; Hunter, Watt, Watt, & Galloway, 2006; McKechnie, Young, & Behm, 2007). However, the majority of the literature has shown that pre-event massage can actually impair muscular strength (Arabacı, 2008; Arroyo-Morales et al., 2011; Fletcher, 2010) and power (Arabacı, 2008; Arazi, Asadi, & Hoseini, 2012; Fletcher, 2010). Arroyo-Morales et al. (2011) found that pre-event massage significantly decreased isokinetic peak torque values for the quadriceps at 240°•s^{-1} and 180 °•s^{-1}. In addition, it was found that pre-event massage negatively affected muscular performance, which was attributed to "increased parasympathetic nervous system activity and decreased afferent input with resultant decreased motor-unit activation" (Arroyo-Morales et al., 2011). Arabaci (2008) found that times for 10-m acceleration and 30-m sprint were decreased following pre-event massage as well as explosive strength measured via vertical jump height.

Some studies have looked at the effects of pre-event massage on alpha motor neuron excitability and the H reflex. However, the vast differences in massage protocol across studies and their lack of similarity to SMR make them difficult to compare to foam rolling. In addition, there is some disagreement whether massage has any acute post-application effect. While some researchers have cited a significant decrease in the H reflex and motor neuron excitability (Behm et al., 2013; S. J. Sullivan, Williams, Seaborne, & Morelli, 1991) others have cited no effect (Dishman & Bulbulian, 2001; Hunter et al., 2006; Morelli, Seaborne, & Sullivan, 1990, 1991). There is no consensus in the literature as to the neurological effects of pre-event massage with respect to motor neuron excitability as measured by the H reflex.

The lack of research into the validity of the physiological mechanisms behind foam rolling, as prescribed by its proponents, and its potential to have detrimental acute effects on muscular performance raise the question: What effect, if any, does foam rolling have on muscular performance?

1.4 Research Questions and Hypotheses

This study aims to investigate the acute effects of foam rolling on explosive strength of the plantar flexors as well as the neuromuscular excitability (as measured by the H-reflex amplitude) in the soleus muscle. Based on findings from related studies on MFR and massage, we expect to see a detrimental acute effect on explosive strength and no effect on the H reflex.

Chapter 2: Methods

2.1 Participants

Data from a total of 21 subjects (14 male, 7 female) were used in this study. Subjects were active and healthy volunteers between the ages of 18-35 yrs with no functional orthopedic or neurological limitations. Subjects were also not foam rolling on a daily basis, did not have an implanted pacemaker, defibrillator, or deep brain stimulator, and all subjects could successfully perform a single leg drop jump with either leg without pain or discomfort.

The primary investigator obtained informed consent from all subjects through a personal interview before data collection. The investigator described all the procedures related to the study and all aspects in which the participant would be involved. The participant then read the consent form and the investigator answered all the participant's questions relating to the experiment. Prior to obtaining the participant's written consent, the participant was asked to orally summarize his/her understanding of the study's involvement to assess his or her comprehension. If the participant understood, both he/she and the investigator signed the consent form. A copy of the consent form was given to each participant. Candidates were told to only sign the consent form if they felt comfortable with its contents. Information disclosed by participants to researchers was coded according to the protocol laid out in the consent form and kept in a locked laboratory for use by researchers only. The researchers agreed to never release any participant/candidate names and participant/candidate materials that could link a participant/candidate to that individual's data unless given written consent by the participant/candidate associated with the materials.

Confidentiality of the research data was guaranteed by maintaining all electronic data, with subject codes rather than participant names, on university encrypted computers secured in university labs by lock and alarm codes. Paper data records were filed and locked in university labs also secured by an alarm code.

2.2 Independent and Dependent Variables

Independent

Sex, test leg assignment, and dominant leg were recorded for subsequent analysis. Sex was chosen because it has been previously shown that men and women may differ in jumping and explosive strength performance (Abián, Alegre, Lara, Rubio, & Aguado, 2008; Healey et al., 2013). The test leg assignment and dominant leg were used to create a new factor named FLeqDL which indicated whether or not the test leg was also the dominant leg. This factor was chosen because it has been previously shown that there is a difference in the H reflex between the trained and non-trained leg (Aagaard, Simonsen, Andersen, Magnusson, & Dyhre-Poulsen, 2002; Aagaard, 2003) which could potentially be reflected in the dominant and non-dominant leg. The third independent variable was treatment with two levels, test leg (FL) and control leg (NL).

Dependent

The dependent variables were H to M ratio (HM) and maximum jump height (JUMP) and explosive strength (RSI) measured from a drop jump onto a force plate. The drop jump was chosen because it is believed to elicit a stretch-shortening cycle (SSC) contraction which activates golgi tendon organs innervated by alpha motor neurons (Flanagan & Comyns, 2008). The drop jump has been previously used in studies investigating explosive strength of the plantar flexors (McKechnie et al., 2007; Power, Behm, Cahill, Carroll, & Young, 2004; W. Young, Elias, & Power, 2006). Explosive strength was measured through the Reactive Strength Index (RSI) by dividing jump height by contact time obtained from the single leg drop jump. The RSI was developed by the Australian Institute of Sport and is thought to be a measure of explosiveness (Flaynagan & Comyns, 2008). It has been used in previous studies as a way of quantifying explosive muscular force (Flanagan & Harrison, 2007; W. Young et al., 2006).

2.3 Equipment

A force plate was used to assess jump height and flight time, and a 30 cm tall box was used for the drop jump. A Grass physiological stimulator and DelSys EMG recording system, along with Vicon data display hardware and software, were used to assess M and H wave amplitude. A homemade foam roller constructed out of polyvinyl chloride (PVC) pipe with a diameter of four inches was used for the intervention. The PVC pipe foam roller was used since it has been suggested that higher density foam rollers may provide more pressure and better isolate the contact area than softer rollers (Curran et al., 2008) potentially increasing the chance in seeing fascial changes. A ½ inch foam yoga mat was placed under the roller to prevent the PVC pipe from slipping on the floor.

2.4 Experimental Procedures

Subjects met with the primary researcher twice. During the first meeting, the primary researcher obtained informed consent and subjects were familiarized with all experimental procedures. For the second meeting, the primary researcher reviewed the experimental protocol with subjects and data were collected. The entire experiment was conducted as follows:

1. Investigator informed candidates of tasks, procedures, and risks and answered any questions.
2. Candidate read and signed consent form and medical questionnaire.

3. Investigator reviewed signed materials to determine if candidate met inclusion criteria.
4. Qualified participants received foam rolling instruction, drop jump practice, and test and control leg were randomly assigned.
5. Subjects were instructed to refrain from moderate to vigorous physical activity (e.g. jogging, playing active sports, biking, swimming, weight lifting) and foam rolling for 24 hours before data collection and on appropriate attire for testing. The testing day was scheduled as well.
6. On testing day, investigator reviewed experimental procedures with subjects.
7. Electrodes were placed on subject and their positions marked by a permanent marker on the skin.
8. H reflex recording and single leg drop jump height were obtained for the test leg (FL).
9. H reflex recording and single leg drop jump height and contact time were obtained for the control leg (NL).
10. EMG electrodes were removed before intervention.
11. An intervention of two minutes and twenty seconds of foam rolling for the FL and rest for the NL were then administered.
12. Subjects then perform a 5 minute warm up on a cycle ergometer.
13. EMG electrodes removed for the intervention were then placed back on their respective points.
14. Repeat 8-9.

2.5 Data Collection

Set-Up

Upon arrival, subjects that did not comply with the 24 hour restrictions were re-scheduled for another testing day. Subjects that did comply were allowed to progress with the experiment. The FL was randomly assigned by coin flip where heads was the left leg and tails was the right. Subject's dominant leg was recorded as the preferred kicking leg. A tape measure was used to determine the length of subject's calf muscle on the FL, taken as the distance between the back of the knee and the lower end of the calf muscle. The researchers then marked four equal sections of subject's leg using a permanent marker. These marks were visible to subjects and served as guidelines for the application of the foam roller. Recording electrodes were placed bilaterally on the soleus muscle; ground electrodes were placed on the medial malleolus of each leg. One stimulating electrode was placed on the patellar tendon and the other over the tibial nerve in the popliteal fossa for each leg. Both the stimulating and recording electrodes were secured with adhesive and the skin was shaved and cleaned prior to application. In addition, electrode locations were marked with a permanent marker after application to ensure correct placement after the foam rolling intervention. Subjects received no warm up prior to testing.

H Reflex

Subjects were seated with the hip at 90 degrees and the knee fully extended. Stimulus duration was set at .5 ms with a monophasic waveform. The stimulating intensity was adjusted for the electrode on the back of the knee until the maximum amplitude for the H wave was reached. The intensity was then increased so the elicited H wave amplitude was 90% of the maximum H wave amplitude. If there was no visible M wave at this intensity, then the intensity was increased until a visible M wave of at least 20% of the max H wave was present. This stimulating intensity was used for data collection and has been used in previous studies (Tokuno, Garland, Carpenter, Thorstensson, & Cresswell, 2008). This stimulus was then applied to the tibial nerve every 10 s and a total of 10 trials were collected. This protocol has been used in previous studies (Allison & Abraham, 1995, 2001; Annaswamy, Mallempati, Allison, & Abraham, 2007). The resulting M and H wave amplitudes were measured for every trial and H to M ratios were used for analysis.

Drop Jump

The drop jump was initiated from a box 30 cm high like that used in previous studies (McKechnie et al., 2007; Power et al., 2004; W. B. Young & Behm, 2003; W. Young et al., 2006; W. Young & Elliott, 2001). Subjects were told to keep their test leg hip extended and their hands on their hips at all times and to land on the force plate. Subjects stepped off the box from the non-test leg and with their test leg straight, landed on the ball of the foot using minimal knee flexion, and then forcefully contracted the plantar flexors of the test leg to achieve maximum possible height. They were told to land after the jump with the hips and knees extended and the feet fully plantar flexed before flexing these joints to distribute the impact of landing (McKechnie et al., 2007). Subjects were told to jump for maximum height and minimal contact time (McKechnie et al., 2007). Two trials were performed with a 30 second rest between trials and the best score was used for analysis (McKechnie et al., 2007). Contact time and flight time were recorded for each trial. Contact time was taken as the instant the force in the z direction became non-zero (initial contact) to the next moment that force in the z direction reached zero (take off). Flight time was taken as the time between take off and the next moment where the force in the z direction was no longer zero (landing). Jump height was calculated using the following equation where g the acceleration due to gravity at 9,81 m/s^2 and t is flight time.

$$jump\ height = \frac{1}{2}\, g \left(\frac{t}{2}\right)^2$$

Explosive strength was quantified using the RSI by dividing jump height by contact time.

Intervention

After initial data collection, the researcher removed the EMG electrodes from the subject's legs before the start of the foam rolling intervention. During the intervention, subjects foam rolled the test leg and rested the control leg (NL) for a total of two minutes and twenty seconds. Subjects were instructed to place the FL on the foam roller and maintain their foot in a fully dorsiflexed position while foam rolling. The NL was crossed over the FL to increase the pressure applied. The foam roller was first placed in the first marked section of the leg closest to the heel. Subjects were instructed to hold the roller on this muscle section for 30 s. A time of 30 s was chosen because it is believed to be an appropriate amount of time to induce the purported fascial changes that take place during foam rolling (Clark & Lucett, 2010). After 30 s of holding, subjects moved the roller back and forth in the same marked section of muscle starting at the distal boundary line, moving to the proximal boundary line, then returning to the distal boundary line. Subjects did this four times at a rate of one cycle per second. Subjects then moved the roller proximally to the next marked section of muscle, held for 30 more s, and then repeated the four cycles within this new section of muscle. This process was repeated for all four marked sections. After subjects had rolled all four sections of muscle, they then moved the foam roller down the leg to the starting point (line closest to the heel) and back again to the boundary line closest to the back of the knee for two cycles at a rate of one cycle every two seconds. This completed the foam rolling intervention. Consistency of holding and rolling times was maintained by using an audible metronome set at 60 beats per minute. Once the foam rolling intervention was finished, subjects performed a 5 minute warm up on a stationary bike. This was done to adhere to current recommendations that foam rolling precede a dynamic warm up before activity (Clark & Lucett, 2010).

Post-Intervention

Once the subjects were done biking, the EMG electrodes were re-applied to the skin in the areas previously outlined with the permanent marker. All measurements and trials were repeated once more. Testing was completed once the second round of measurements was done. The only difference in protocol was that for the H reflex testing, the new stimulating intensity was adjusted so that the post-intervention M wave was similar in amplitude to the pre-intervention M wave. The foam rolling leg was always tested before the control leg in order to keep equal time intervals between pre-test measurements and post-test measurements and in an attempt to measure the immediate acute effects of foam rolling post-intervention.

Data Analysis

Of the 21 individuals tested, 15 subjects (9 male, 6 female) were included for HM ratio analysis and 19 subjects (12 male, 7 female) were included in the jump height and explosive strength analysis. A repeated measures ANOVA with a two between and one within subject factors design was used to test for significance. The designated between subject factors were gender (SEX) and whether or not the subject's FL was also the reported dominant leg (FLeqDL). Separate repeated measures ANOVAs were ran for each variable with significance taken at alpha = .05.

HM Ratio Analysis

The M wave amplitude was taken as the peak-to-peak difference from 10 ms to 30 ms after the stimulus onset. Corresponding H wave amplitude was taken as the peak-to-peak difference from 40 ms to 60 ms after the stimulus onset. Before ratio analysis, a t-test was used to determine whether or not the pre and post test average M waves within each leg were considered to be significantly different. If the pre and post average M waves yielded a significant t-test at alpha = .05, then the waveform containing the M wave with the highest deviation from the combined mean of the pre and post tests was eliminated from the data set. This process was repeated until there was no significant difference between the pre and post test means. If there were less than six remaining waveforms in any trial for any data set, then the entire data was determined to be unreliable and the subject was not included in the analysis.

The HM ratio was then calculated by dividing each H wave amplitude by its corresponding M wave amplitude. The ratios were then averaged for each trial and each leg yielding four separate ratios. The difference between the pre and post test was calculated by subtracting the average pre-test ratio from the post-test ratio. This difference was then divided by the pre-test ratio in order to standardize the data across subjects. Complete analysis of the raw data produced two standardized values per subject, one for the test leg (FL) and one for the control leg (NL). These two values were calculated for each subject then used for statistical analysis in the repeated measures ANOVA.

Jump Height and RSI

The best pre and post test score was used for analysis. Data was standardized by subtracting the pre test from the post-test, then dividing by the pre-test. Complete analysis yielded two values for jump height and power (one for the FL and one for the

NL) for each subject. These values were then compared for each variable using the 2x2x2 repeated measures ANOVA.

Chapter 3: Results

A 2x2x2 factor ANOVA with repeated measures on the last factor was ran for HM, JUMP, and RSI. The hypotheses were that foam rolling will have no effect on HM and that foam rolling will have a negative effect on JUMP and RSI as compared to the control. Analysis revealed no significant differences between the foam rolling leg (FL) and the control leg (NL) on any of the measured variables nor any significant interaction effects (see Tables 2-4). Both power and jump height decreased post intervention regardless of treatment. However, the FL trended towards a greater decrease in power and jump height than the NL but this was not significant. In addition, although not significant, the FL trended towards an increase in the HM ratio while the NL showed a possible decrease.

Dependent Variable	Leg	Mean Post/Pre Ratio	Standard Error
HM	FL	1.071	.163
	NL	.981	.102
JUMP	FL	.835	.055
	NL	.896	.065
RSI	FL	.858	.06
	NL	.894	.055

Table 1: Post/pre treatment means and standard error of the means

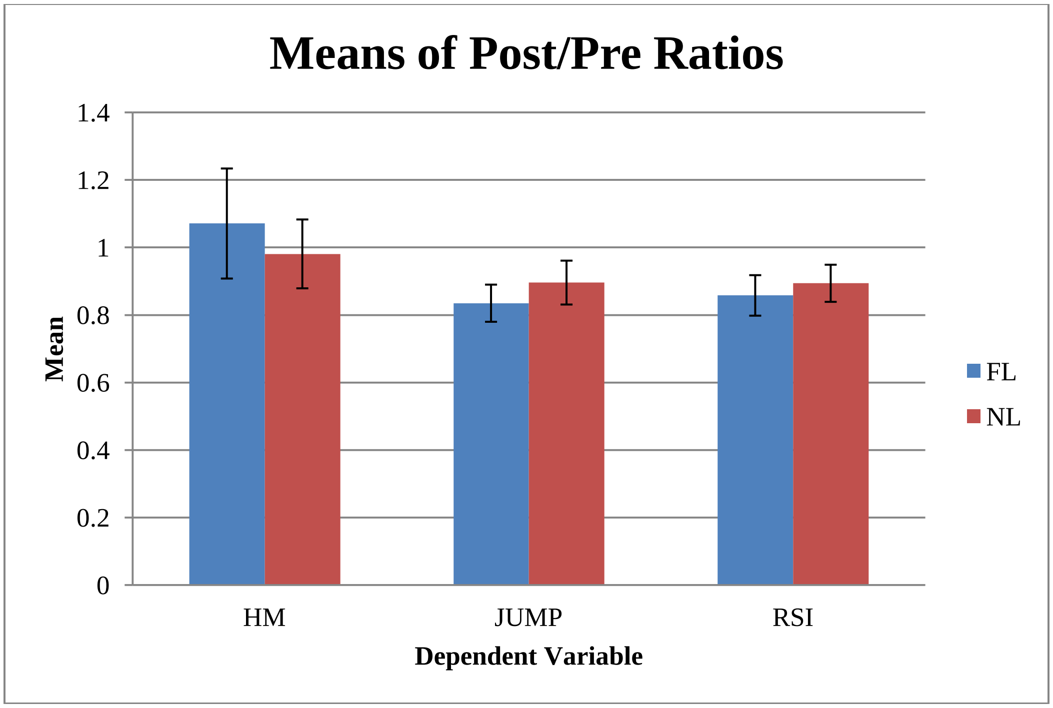

Figure 3: Graph of post/pre ratio means

HM Ratio			
Measure	p	Partial Eta Squared	Power
FLNL	.660	.018	.070
FLNL*SEX	.830	.004	.055
FLNL*FLeqDL	.803	.006	.056

Table 2: Statistical data for HM analysis

JUMP			
Measure	p	Partial Eta Squared	Power
FLNL	.525	.028	.094
FLNL*SEX	.318	.066	.162
FLNL*FLeqDL	.646	.014	.072

Table 3: Statistical data for JUMP analysis

RSI			
Measure	p	Partial Eta Squared	Power
FLNL	.693	.011	.066
FLNL*SEX	.352	.058	.147
FLNL*FLeqDL	.576	.021	.048

Table 4: Statistical data for RSI analysis

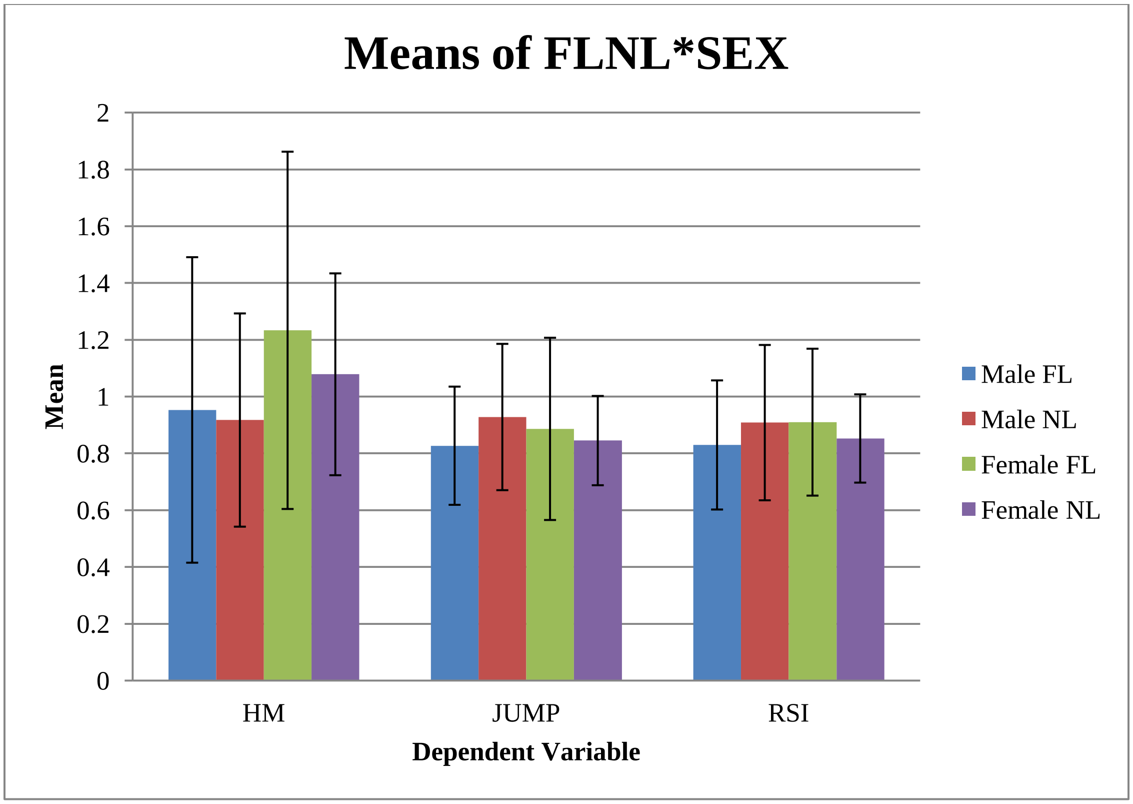

Figure 4: Means of FLNL*SEX interaction effect

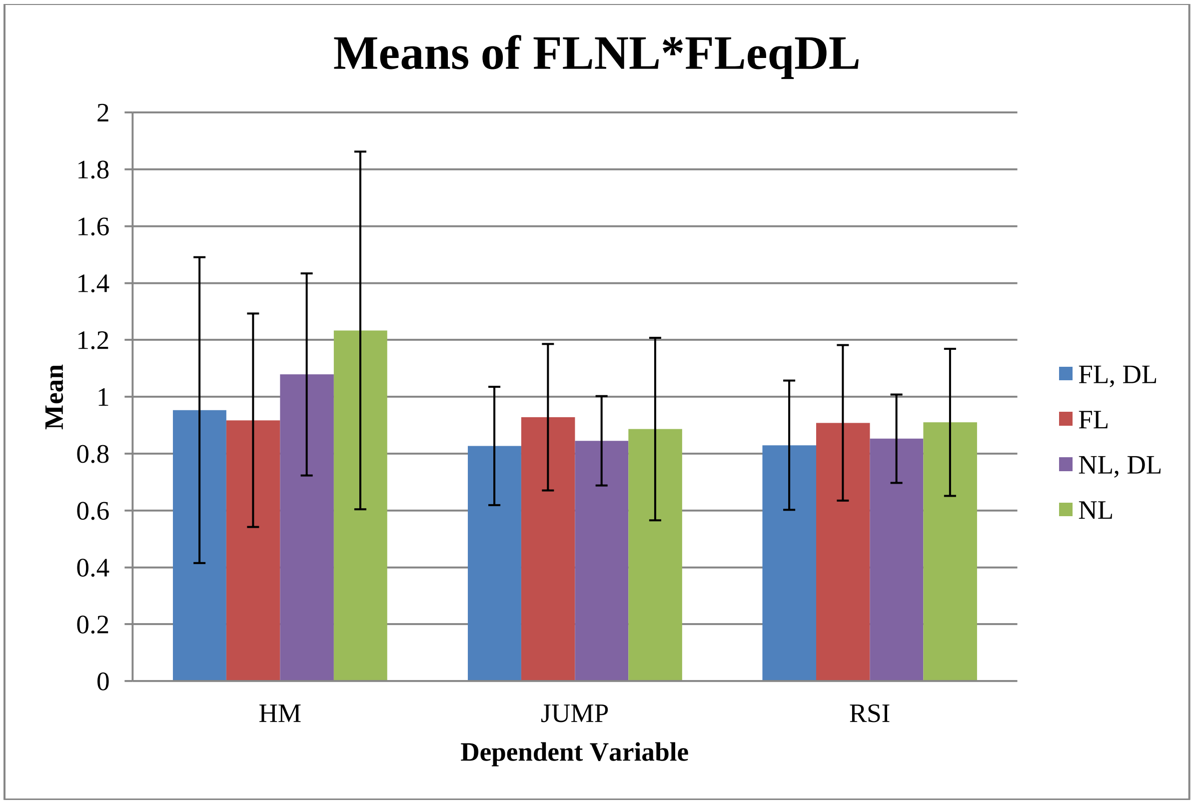

Figure 5: Means of FLNL*FLeqDL. DL is dominant leg assignment

Overall analysis of the data revealed no significant difference between the treatment and control legs.

Chapter 4: Discussion

The purpose of this study was to investigate the acute effects of foam rolling on explosive strength and excitability of the motor neuron pool. With respect to explosive strength, this study found that our foam rolling protocol did not induce any significant changes to jump height or explosive strength of the plantar flexors. In addition, the foam rolling protocol utilized in this study had no significant effect on the excitability of the motor neuron pool. There also appears to be no relationship between gender or leg dominance on any of the experimental measures.

The results support our original hypothesis that foam rolling will have no effect on HM ratios. Our findings are the similar to those in related pre-event massage studies (Dishman & Bulbulian, 2001; Hunter et al., 2006; Morelli et al., 1990, 1991) as well as those in Sullivan et al. (2013) who found that an acute bout of foam rolling had no effect on maximal voluntary contraction, electromechanical decay, and evoked twitch force on the quadriceps. However, this does not eliminate the possibility that foam rolling does produce an immediate effect on alpha motor neuron excitability that was not detected in this experiment. While some massage research found an acute change in the H reflex post application (Behm et al., 2013; S. J. Sullivan et al., 1991) others have shown that changes in the H reflex are only visible during application and immediately return to baseline once the massage is terminated, regardless of time of massage intervention (Morelli et al., 1990, 1991). Future research should be done to see whether or not this phenomenon occurs during foam rolling.

As a result of our findings on HM ratios, we conclude that there is not sufficient evidence to support the claim that foam rolling facilitates the removal of trigger points through influencing alpha motor neurons. While one current theory is that foam rolling removes trigger points by stimulating interstitial receptors that respond to both light touch and deep sustained pressure (Schleip, 2003b), previous research on massage has shown that stimulation of deep mechanoreceptors is the most likely the cause of changes in the H reflex (Morelli, Chapman, & Sullivan, 1999). In addition, the massage studies that did find a post application change in the H reflex utilized massage techniques that involve a hitting or beating technique designed to affect deep tissue and thus would be more likely to stimulate deep mechanoreceptors. If this is the case, then perhaps foam rolling, as done in this experiment, does not produce the minimum forces necessary to stimulate these deep receptors. However, two subjects with masses above the average mass of 72.3 ± 15.5 kg (82.5 kg and 77.1 kg) showed an increase in the FL HM ratio while two subjects below the average mass (47.7 kg and 64.2 kg) showed a decrease in the FL HM ratio. If foam rolling has the potential to stimulate the deep mechanoreceptors responsible for alteration of alpha motor neuron excitability, then subjects with higher masses should be theoretically more likely to produce a decrease in the HM ratio. While this trend was not observed for our results, this study lacked sufficient data to run any statistical tests on the relationship between weight and HM ratio results. Sullivan et al. (2013) found that the average mass component of force exerted by a foam roller on the hamstrings for an individual supported by body weight was 13 kg. While the study found significant short term changes to range of motion when this force was applied to all subjects, regardless of body weight, they did not record the H reflex or any measure of explosive strength. Thus, it is impossible to say whether or not the average mass component of force of 13 kg is enough to stimulate the deep mechanoreceptors. Future studies should investigate the relationship between the force needed to stimulate deep receptors and the force exerted by body weight on a foam roller.

With respect to jump height and RSI, the results do not support our hypothesis that foam rolling will have a negative effect on explosive strength. This is contrary to the findings in related massage studies that cited negative effects to explosive strength (Arabacı, 2008; Arazi et al., 2012; Fletcher, 2010). One reason for this could be that the foam rolling protocol did not supply enough force to the treatment area to induce the appropriate fascial changes, as previously described. This is not solely limited to stimulation of the deep mechanoreceptors, but also purported mechanical and structural changes in the fascia which would affect jump height and RSI. Threlkeld (1992) claimed that the mass component of force needed for partial mechanical deformation and ultimately elongation of the fascia was between 24-115 kg. If the foam rolling protocol failed to meet this minimum then this might explain why there were no differences in jump height and RSI. Even if the minimums cited in Threlkeld were met it would only create partial deformation in the fascia. This creates a plausible explanation as to why certain foam rolling studies have cited an increase in range of motion with no concurrent detriments to muscular performance (Healey et al., 2013; Macdonald et al., 2012) and why the results for jump height in this study were similar to those in Healey et al. (2013).

Another reason could be the duration of the hold in the foam rolling protocol. Current SMR recommendations call for the user to hold the foam roller on an area of tense muscle for 30 s (Clark & Lucett, 2010; Lavelle et al., 2007; Schleip, 2003a) or until a release is felt (Lavelle et al., 2007; Schleip, 2003a). It is possible that related impairments to muscular performance only occur with longer application times. Healey et al. found a statistically significant relationship between increased time of foam rolling application and increase in range of motion of the hamstrings but no concurrent changes in MVC force or EMG MVC. However, the foam rolling protocol required consistent rolling for a maximum of two 10 second bouts and did not incorporate any holds.

The possibility also exists that foam rolling is incapable of producing the same effects as those seen in myofascial release solely because of the method of application. In myofascial release performed by a practitioner, pressure is usually applied through the thumb, elbow, hands, or other tools with a smaller area than a traditional foam roller. It could be that pressure applied to the contact area plays more of a role than force applied. This would explain why a decrease in basal myoelectrical activity, which reflects a change in alpha motor neuron excitability, was seen in both MFR studies (Aguilera et al., 2009; Montañez-Aguilera et al., 2010) but was not seen in the results of this study. Perhaps foam rollers or other SMR products with smaller contact areas would be more likely to cause changes in alpha motor neuron excitability and muscular performance.

Analysis of the between subject factors indicated that there were no significant interaction effects between dominant leg assignment and HM. This is contrary to the previous findings which indicate a significant effect of leg dominance on neuromuscular function (Aagaard et al., 2002; Aagaard, 2003).

The findings of this study indicate that 2.5 min of foam rolling immediately followed by a dynamic warm up does not elicit any acute changes to alpha motor neuron excitability or muscular performance. Future foam rolling studies should investigate the relationship between contact pressure and force applied, and to changes in range of motion with concurrent assessments of explosive strength.

References

Aagaard, P. (2003). Training-induced changes in neural function. *Exercise and sport sciences reviews*, *31*(2), 61–67.

Aagaard, P., Simonsen, E. B., Andersen, J. L., Magnusson, P., & Dyhre-Poulsen, P. (2002). Neural adaptation to resistance training: changes in evoked V-wave and H-reflex responses. *Journal of applied physiology (Bethesda, Md.: 1985)*, *92*(6), 2309–2318. doi:10.1152/japplphysiol.01185.2001

Abián, J., Alegre, L. M., Lara, A. J., Rubio, J. A., & Aguado, X. (2008). Landing differences between men and women in a maximal vertical jump aptitude test. *The Journal of sports medicine and physical fitness*, *48*(3), 305–310.

Aguilera, F., Martin, D., Masanet, R., Botella, A., Soler, L., & Morell, F. (2009). Immediate effect of ultrasound and ischemic compression techniques for the treatment of trapezius latent myofascial trigger points in healthy subjects: a randomized controlled study. *Journal of Manipulative Physiological Therapy*, *32*(7), 515–520.

Allison, S., & Abraham, L. (1995). Correlation of quantitative measures with the modified Ashworth scale in the assessment of plantar flexor spasticity in patients with traumatic brain injury. *Journal of Neurology*, *242*, 699–706.

Allison, S., & Abraham, L. (2001). Sensitivity of qualitative and quantitative spasticity measures to clinical treatment with cryotherapy. *International Journal of Rehabilitation Research*, *24*, 15–24.

Annaswamy, T., Mallempati, S., Allison, S., & Abraham, L. (2007). Measurement of plantarflexor spasticity in traumatic brain injury: correlational study of resistance torque compared with the modified Ashworth scale. *American Journal of Physical Medicine & Rehabilitation*, *86*, 404–411.

Arabacı, R. (2008). Acute effects of pre-event lower limb massage on explosive and high speed motor capacities and flexibility. *Journal of Sport Science and Medicine*, *7*, 549–555.

Arazi, H., Asadi, A., & Hoseini, K. (2012). Comparison of two different warm ups (static-stretching and massage): effects on flexibility and explosive power. *Acta Kinesiologica*, *6*(1), 55–59.

Arroyo-Morales, M., Fernández-Lao, C., Ariza-García, A., Toro-Velasco, C., Winters, M., Díaz-Rodríguez, L., … Fernández-De-las-Peñas, C. (2011).

Psychophysiological effects of preperformance massage before isokinetic exercise. *Journal of strength and conditioning research / National Strength & Conditioning Association*, *25*(2), 481–488. doi:10.1519/JSC.0b013e3181e83a47

Badenhausen, K., Ozanian, M., & Settimi, C. (2010, August 25). The Most Valuable NFL Teams. *Forbes*. Retrieved August 11, 2013, from http://www.forbes.com/2010/08/25/most-valuable-nfl-teams-business-sports-football-valuations-10-intro.html

Behm, D. G., Peach, A., Maddigan, M., Aboodarda, S. J., Disanto, M. C., Button, D. C., & Maffiuletti, N. A. (2013). Massage and stretching reduce spinal reflex excitability without affecting twitch contractile properties. *Journal of electromyography and kinesiology: official journal of the International Society of Electrophysiological Kinesiology*. doi:10.1016/j.jelekin.2013.05.002

Berg, F. van den, & Cabri, J. (1999). *Angewandte Physiologie, Bd.1, Das Bindegewebe des Bewegungsapparates verstehen und beeinflussen*. Thieme, Stuttgart.

Brummitt, J. (2008). The Role of Massage in Sports Performance and Rehabilitation: Current Evidence and Future Direction. *North American Journal of Sports Physical Therapy : NAJSPT*, *3*(1), 7–21.

Budget Facts. (2011, May 16). *Budget 101*. Retrieved August 11, 2013, from http://www.utexas.edu/finances/budgetfacts.html

Clark, M., & Lucett, S. (2010). *NASM Essentials of Corrective Exercise Training* (1 Har/Psc.). Lippincott Williams & Wilkins.

Curran, P. F., Fiore, R. D., & Crisco, J. J. (2008). A comparison of the pressure exerted on soft tissue by 2 myofascial rollers. *Journal of sport rehabilitation*, *17*(4), 432–442.

Delaney, J. P. A., Leong, K. S., Watkins, A., & Brodie, D. (2002). The short-term effects of myofascial trigger point massage therapy on cardiac autonomic tone in healthy subjects. *Journal of advanced nursing*, *37*(4), 364–371.

Dishman, J. D., & Bulbulian, R. (2001). Comparison of effects of spinal manipulation and massage on motor neuron excitability. *Electromyography and clinical neurophysiology*, *41*(2), 97–106.

Flanagan, E. P., & Comyns, T. M. (2008). The Use of Contact Time and the Reactive Strength Index to Optimize Fast Stretch-Shortening Cycle Training. *Strength & Conditioning Journal*, *30*(5), 32–38. doi:10.1519/SSC.0b013e318187e25b

Flanagan, E. P., & Harrison, A. J. (2007). Muscle dynamics differences between legs in healthy adults. *Journal of strength and conditioning research / National Strength & Conditioning Association*, *21*(1), 67–72. doi:10.1519/R-18495.1

Fletcher, I. M. (2010). The effects of precompetition massage on the kinematic parameters of 20-m sprint performance. *Journal of strength and conditioning research / National Strength & Conditioning Association*, *24*(5), 1179–1183. doi:10.1519/JSC.0b013e3181ceec0f

Gossman, M. R., Sahrmann, S. A., & Rose, S. J. (1982). Review of length-associated changes in muscle. Experimental evidence and clinical implications. *Physical therapy*, *62*(12), 1799–1808.

Healey, K. C., Hatfield, D. L., Blanpied, P., Dorfman, L. R., & Riebe, D. (2013). The Effects of Myofascial Release with Foam Rolling on Performance. *Journal of strength and conditioning research / National Strength & Conditioning Association*. doi:10.1519/JSC.0b013e3182956569

Hunter, A. M., Watt, J. M., Watt, V., & Galloway, S. D. R. (2006). Effect of lower limb massage on electromyography and force production of the knee extensors. *British journal of sports medicine*, *40*(2), 114–118. doi:10.1136/bjsm.2005.019075

Johansson, B. (1962). Circulatory response to stimulation of somatic afferents. *Acta Physiologica*, *198*, 1–92.

Lavelle, E. D., Lavelle, W., & Smith, H. S. (2007). Myofascial trigger points. *The Medical clinics of North America*, *91*(2), 229–239. doi:10.1016/j.mcna.2006.12.004

Lin, M.-T., Chou, L.-W., Chen, H.-S., & Kao, M.-J. (2012). Percutaneous soft tissue release for treating chronic recurrent myofascial pain associated with lateral epicondylitis: 6 case studies. *Evidence-based Complementary and Alternative Medicine*, *2012*, 142941. doi:10.1155/2012/142941

Macdonald, G., Penney, M., Mullaley, M., Cuconato, A., Drake, C., Behm, D. G., & Button, D. C. (2012). An Acute Bout of Self Myofascial Release Increases Range of Motion Without a Subsequent Decrease in Muscle Activation or Force. *Journal of strength and conditioning research / National Strength & Conditioning Association*. doi:10.1519/JSC.0b013e31825c2bc1

McKechnie, G. J., Young, W. B., & Behm, D. G. (2007). Acute effects of two massage techniques on ankle joint flexibility and power of the plantar flexors. *Journal of Sports Science and Medicine*, *6*(4), 498–504.

Mitchell, J. H., & Schmidt, R. F. (2011). Cardiovascular Reflex Control by Afferent Fibers from Skeletal Muscle Receptors. In R. Terjung (Ed.), *Comprehensive Physiology*. Hoboken, NJ, USA: John Wiley & Sons, Inc. Retrieved from http://www.comprehensivephysiology.com/WileyCDA/CompPhysArticle/refId-cp020317.html

Montañez-Aguilera, F. J., Valtueña-Gimeno, N., Pecos-Martín, D., Arnau-Masanet, R., Barrios-Pitarque, C., & Bosch-Morell, F. (2010). Changes in a patient with neck pain after application of ischemic compression as a trigger point therapy. *Journal of back and musculoskeletal rehabilitation*, *23*(2), 101–104. doi:10.3233/BMR-2010-0255

Morelli, M., Chapman, C. E., & Sullivan, S. J. (1999). Do cutaneous receptors contribute to the changes in the amplitude of the H-reflex during massage? *Electromyography and clinical neurophysiology*, *39*(7), 441–447.

Morelli, M., Seaborne, D. E., & Sullivan, S. J. (1990). Changes in h-reflex amplitude during massage of triceps surae in healthy subjects. *The Journal of orthopaedic and sports physical therapy*, *12*(2), 55–59.

Morelli, M., Seaborne, D. E., & Sullivan, S. J. (1991). H-reflex modulation during manual muscle massage of human triceps surae. *Archives of physical medicine and rehabilitation*, *72*(11), 915–919.

Okamoto, T., Masuhara, M., & Ikuta, K. (2013). Acute Effects of Self-Myofascial Release Using a Foam Roller on Arterial Function. *Journal of strength and conditioning research / National Strength & Conditioning Association*. doi:10.1519/JSC.0b013e31829480f5

Power, K., Behm, D., Cahill, F., Carroll, M., & Young, W. (2004). An acute bout of static stretching: effects on force and jumping performance. *Medicine and science in sports and exercise*, *36*(8), 1389–1396.

Renaud, A. [Untitled photograph of various foam rollers]. Retrieved August 1, 2013, from: http://www.golf-fitness-and-trainingtips.com/foamroller.html#s thash.iM6pc34m.dpbs

Roach, S., Sorenson, E., Headley, B., & San Juan, J. G. (2012). Prevalence of Myofascial Trigger Points in the Hip in Patellofemoral Pain. *Archives of physical medicine and rehabilitation*. doi:10.1016/j.apmr.2012.10.022

Schleip, R. (2003a). Fascial plasticity---a new neurobiological explanation: Part 1. *Journal of Bodywork and Movement Therapy*, *7*(1), 11–19.

Schleip, R. (2003b). Fascial plasticity---a new neurobiological explanation: Part 2. *Journal of Bodywork and Movement Therapy*, *7*(2), 104–116.

Sullivan, K. M., Silvey, D. B. J., Button, D. C., & Behm, D. G. (2013). ROLLER-MASSAGER APPLICATION TO THE HAMSTRINGS INCREASES SIT-AND-REACH RANGE OF MOTION WITHIN FIVE TO TEN SECONDS WITHOUT PERFORMANCE IMPAIRMENTS. *International Journal of Sports Physical Therapy*, *8*(3), 228–236.

Sullivan, S. J., Williams, L. R., Seaborne, D. E., & Morelli, M. (1991). Effects of massage on alpha motor neuron excitability. *Physical therapy*, *71*(8), 555–560.

Threlkeld, A. J. (1992). The effects of manual therapy on connective tissue. *Physical therapy*, *72*(12), 893–902.

Tokuno, C. D., Garland, S. J., Carpenter, M. G., Thorstensson, A., & Cresswell, A. G. (2008). Sway-dependent modulation of the triceps surae H-reflex during standing. *Journal of Applied Physiology*, *104*(5), 1359–1365. doi:10.1152/japplphysiol.00857.2007

[Untitled photograph of foam rolling positions]. Retrieved August 1, 2013, from: http://gypsy-fit.com/foam-roller-exercises/

Young, W. B., & Behm, D. G. (2003). Effects of running, static stretching and practice jumps on explosive force production and jumping performance. *The Journal of sports medicine and physical fitness*, *43*(1), 21–27.

Young, W., Elias, G., & Power, J. (2006). Effects of static stretching volume and intensity on plantar flexor explosive force production and range of motion. *The Journal of sports medicine and physical fitness*, *46*(3), 403–411.

Young, W., & Elliott, S. (2001). Acute effects of static stretching, proprioceptive neuromuscular facilitation stretching, and maximum voluntary contractions on explosive force production and jumping performance. *Research quarterly for exercise and sport*, *72*(3), 273–279.